MOISTURE AND COTTON AT HARVEST TIME IN THE MISSISSIPPI DELTA

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ABSTRACT

The moisture content of cotton at time of harvest has a direct effect on cotton quality. Weather, in particular relative humidity, strongly influences variation in cotton moisture content. This paper summarizes three years of observations of weather in and around cotton fields at harvest time in the Mississippi Delta.

Detailed studies of the variation of relative humidity, temperature, wind, sunlight, dew, and evaporation have been made in leafed fields and in fields where leaves were removed artificially. Single weather variables and combinations of variables have been related to dew intensity and to the rate of evaporation. Surface weather maps are presented to show the average pressure patterns associated with extremes in dew and evaporation. A preliminary cotton picking guide, developed jointly by the Weather Bureau and the Cotton Harvesting Section of the U.S. Department of Agriculture, which gives the farmer an objective estimate of when to start picking cotton on the basis of weather variation, illustrates how weather information can improve farm efficiency.

1. INTRODUCTION

Dry weather is good cotton picking weather. In the humid Cotton Belt, over 8 million bales with a cash value of over a billion dollars were harvested in 1959. Some of this cotton was harvested too wet and the consequent reduction in quality resulted in a price drop of $10 to $15 per bale; thus damp cotton in the humid belt is a problem of considerable economic importance.

Wet weather in the form of excessive rain gives poor harvest conditions; mechanical equipment is inoperative when soils are water-logged; if the rain persists, maturity may be delayed until the plants are caught by frost; and frequent soaking of lint by rain stains the cotton. This type of wet weather damage has no control. Wet weather in the form of high humidity is damaging to quality if the cotton is picked while wet. If the cotton is not harvested until the lint has dried, higher quality results. This type of wet weather damage does have a control; a harvest program that restricts operations to periods of optimum moisture conditions of cotton on the stalk.

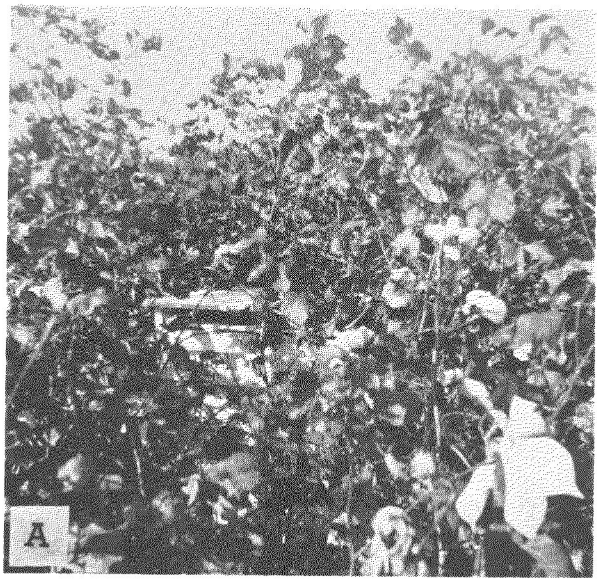
When cotton is picked too wet or with a seed cotton moisture content above about 10 percent, staining is more frequent and more trash adheres to the lint [1,2]. By the middle of the harvest season, most gins are overloaded and many trailer loads of cotton are kept waiting at the gin yard. The delay accelerates bacterial activity which causes increased discoloration and general deterioration of fiber and seed. After wet cotton reaches the gin, fairly high temperatues are necessary for drying the lint to an acceptable moisture level. This makes the fiber brittle and staple length is often reduced.

Research has shown that relative humidity exerts the greatest control over seed cotton moisture variation with the exception of actual rainfall. Wooten and Montgomery found that after a morning dew a relative humidity of approximately 50 percent is the dividing line between cotton dry enough to pick and cotton that is too wet. Under the usual harvest weather conditions, relative humidity can be used to give a realistic estimate of the seed cotton moisture content on the stalk [3,4].

Defoliation, or the removal of leaves by chemical application, is now practiced on over half of the cotton acreage in the humid belt. Its original purpose was to reduce leaf trash gathered by the ever increasing number of mechanical pickers [5]. In the last few years, it has been recognized as an aid in reducing the moisture content of seed cotton [6]. This study illustrates the change in microclimate that results in cotton fields from defoliation.

The objective of this study is the development of an understanding of moisture variation within cotton fields which will form the basis of a technique for forecasting "safe" picking conditions.

The history of weather observation programs designed to increase the efficiency of the cotton industry dates back many years. The Organic Act of the Weather Bureau enacted in 1890 states its mission in part as ". . . the reporting of temperature and rainfall conditions for the cotton interests . . ." This Act is still in effect and its most



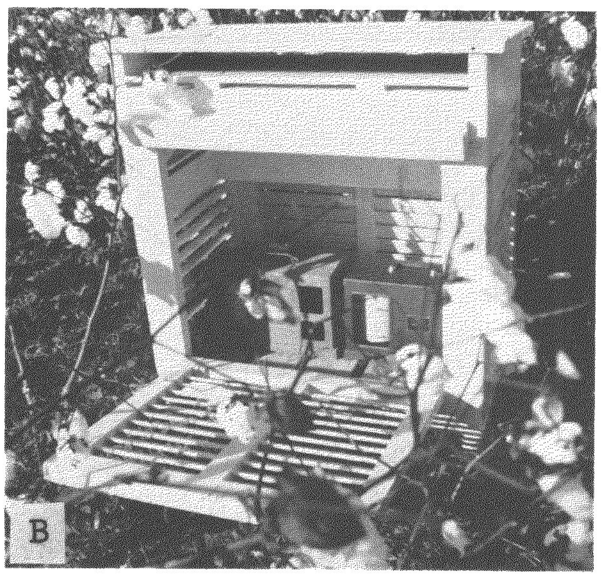


FIGURE 1.—Hygrothermographs in (A) leafed and (B) defoliated cotton fields.

recent implementation is the Delta Agricultural Weather Project, under which the work reported here was done. This study summarizes observations and tests made in cotton fields during the fall seasons of 1958 through 1960. All tests were made in cooperation with the Cotton Harvesting Section of the U.S. Department of Agriculture and the Delta Branch of the Mississippi Agricultural Experiment Station.

Observations were made in Delta Experiment Station cotton fields about one mile south of the Administration Building. The area is free from obstructions and typical of most Delta cotton fields. Deer Creek makes a wide loop around the area at a distance of about 0.4 mile north of the observation site, 0.8 mile to the east, and 0.3 mile to the south. Trees about 50 feet high are scattered along the creek. Measurements were made in both defoliated and undefoliated cotton fields with similar crop cover extending several hundred yards in all directions from the instrument site.

TABLE 1.—*Cross section of leaf, stalk and lint in square feet per cubic foot of space occupied by defoliated and undefoliated cotton plants.*

Leaf cover	Leaf area	Stalk and lint area	Total area
Defoliated	2.5	16.5	19.0
Undefoliated	110.5	16.5	127.0

Because of the remarkably uniform growth characteristics of cotton grown in this experimental field and the scientific farming practices, cotton stands of great similarity were available for microweather observations during the three fall seasons. The average height of the cotton plants did vary slightly: in 1958–59 cotton averaged 5 feet high and in 1960, 4 feet. Leaf density was very similar; table 1 shows the 3-year average values of leaf, and stalk and lint cross-section area in square feet for each cubic foot of space occupied by plants. The leaf area, or the area available for transpiration, in the defoliated field was only 2 percent of the leaf area in the undefoliated field. The total area of leaf, stalk and lint, or the area available for obstruction to wind and sunlight, in the defoliated field was 15 percent of the area in the undefoliated.

2. RELATIVE HUMIDITY AND TEMPERATURE

Relative humidity shows considerable variation in cotton fields and in turn is a key to the variation in seed cotton moisture. The air surrounding cotton plants receives vapor from the transpiring plants, evaporation from moist soil and rainfall, and from mixing with moist air moving northward from the Gulf of Mexico. At night, the air frequently loses water vapor by dew formation but this is usually returned the following day by evaporation. Vapor losses of more importance occur with rising air currents, especially when accompanied by strong dry winds. Most of the diurnal variation in relative humidity, which is an important variable in designing a picking program, is caused by variation in temperature rather than in absolute content of moisture.

Hygrothermographs were placed in instrument shelters at a height of 10 inches above the ground (see fig. 1) and at 54 inches above the ground (top of cotton averaged 60 inches) in both defoliated and undefoliated cotton fields. Table 2 shows the average daily minimum relative humidity and maximum and minimum temperature and temperature range for 35 days without rain from September 22–November 5, 1959.

The minimum daily humidity deep within the plant zone averaged 9 percent lower in the defoliated field than in the leafed field. At the top of the plant zone, relative humidity was slightly higher in the defoliated field. Highest maximum temperatures, which are approximately concurrent with minimum relative humidity, occurred in

TABLE 2.—*Average daily minimum relative humidity and maximum and minimum temperature and temperature range for 35 days without rain from Sept. 22–Nov. 5, 1959, Stoneville, Miss.*

Exposure	Minimum relative humidity	Maximum temperature	Minimum temperature	Temperature range
	Percent	*°F.*	*°F.*	*°F.*
54-inch undefoliated	48.0	75.0	57.8	17.2
10-inch undefoliated	56.8	74.3	57.9	16.2
54-inch defoliated	48.8	79.6	58.0	18.4
10-inch defoliated	47.7	80.9	57.4	23.5

the defoliated field. The largest temperature range was at the low level in the defoliated field and the smallest range was within the plant cover of the leafed field.

The vertical variation of relative humidity in the defoliated field was similar to the variation that occurs above bare ground. In this case, the relative humidity was slightly less near the ground than at the top of the plant. Geiger [7] calls this distribution the "dry type" and indicates that it is very rare, and indeed, he stated that it has been observed only in southern India, particularly over the black cotton soils. It is possible that the instruments used in this experiment are not precise enough to detect a 1 percent difference; however, it was unusual that the relative humidity was not higher near the ground.

The variation in relative humidity in a leafed field is mainly the result of exposure. The low level is sheltered from the sun and wind; thus moisture is not as free to disperse into the atmosphere as from the top of the plant zone. A smaller effect is the lower temperatures caused by shading. Using the 1959 data as an example (table 2), if the maximum temperature of 74.3° F. observed at the 10-inch level were raised to 75.0° F. (the maximum at 54 inches), the relative humidity of the air parcel would be reduced less than one percent. Since the difference in relative humidity between the two levels was actually 8.8 percent, the difference in temperature alone cannot account for the measured difference. The higher humidity at the low level must have been caused by the lack of mixing with drier air above the plant zone.

Observations made during the fall seasons of 1958 and 1960 conformed in pattern to the detail given above for 1959. For the 3-year period, the relative humidity averaged between 8 and 10 percent higher within the plant zone of the leafed field, and the humidity remained below 50 percent for one additional hour in the defoliated field.

3. WIND AND SUNLIGHT

Wind variation.—Air movement acts in both the vertical and the horizontal plane to change the moisture level on and near cotton plants. Wind can completely change temperature and moisture characteristics of air surrounding cotton plants at times of air mass change and cause minor modifications at other times. Vertical air movement mixes the air near the plant with air of differing characteristics at some height above the ground.

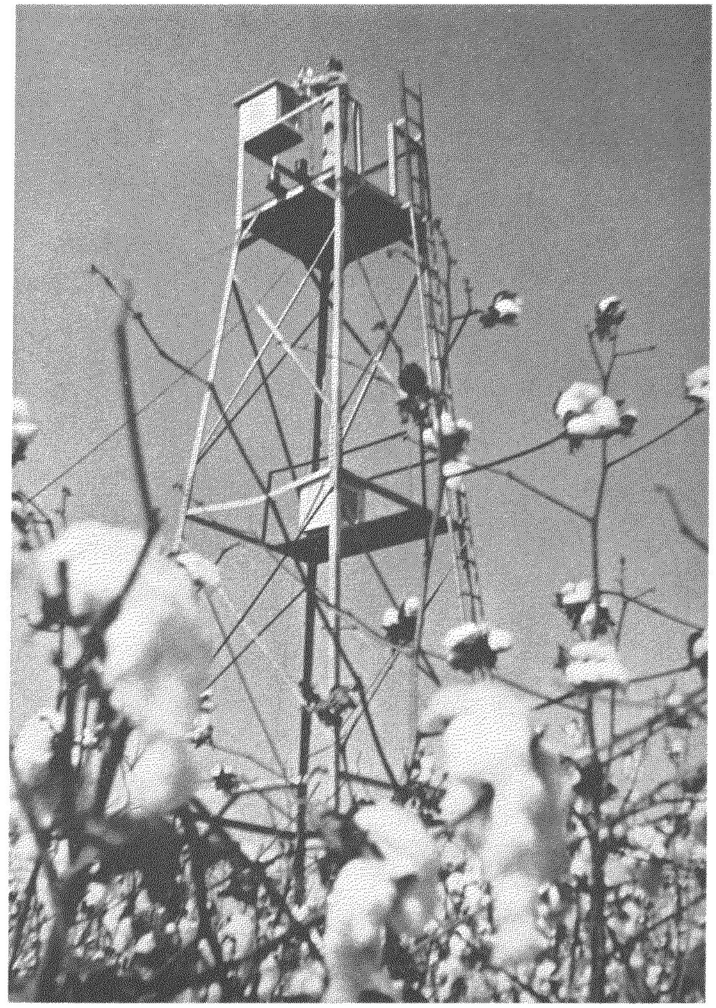


FIGURE 2.—Weather tower in cotton field. Anemometer, hygrothermograph, and Livingston atmometers located on top of tower.

Vertical air movement was not measured directly; however, the air stability which is related to vertical movement was measured. The temperature at 5 feet above the ground minus the temperature at 35 feet was the measurement of air stability used in this study. When the difference was positive, i.e., the temperature near the ground was higher than the temperature at the upper level, the air was more likely to undergo vertical motion by way of turbulent eddies. In this portion of the report, stability and wind are represented by daytime average (7 a.m. to 5 p.m. LST) and nighttime average (5 p.m. to 7 a.m. the next morning). From September 30–November 8, 1960, the daytime stability averaged +1.45° and the nighttime stability, −2.18°; consequently vertical motion was much more of a factor in the daytime than at night.

The wind was measured at 40 feet above the ground on top of the observation tower shown in figure 2 and at 7 feet above the ground which was 3 feet above the defoliated

FIGURE 3.—Anemometer, instrument shelter, and Livingston atmometer (observer refilling atmometer) in cotton fields.

cotton tops shown in figure 3. The wind on the tower averaged 5.27 m.p.h. and at the lower level averaged 2.45 m.p.h. During the daytime, the upper wind averaged 6.50 m.p.h and the lower 3.65 m.p.h.; thus, the lower level was 56 percent of the upper level. At night, the wind averaged 4.40 m.p.h. at the upper level and 1.55 m.p.h. at the lower level. At night the lower wind was only 35 percent of the upper level.

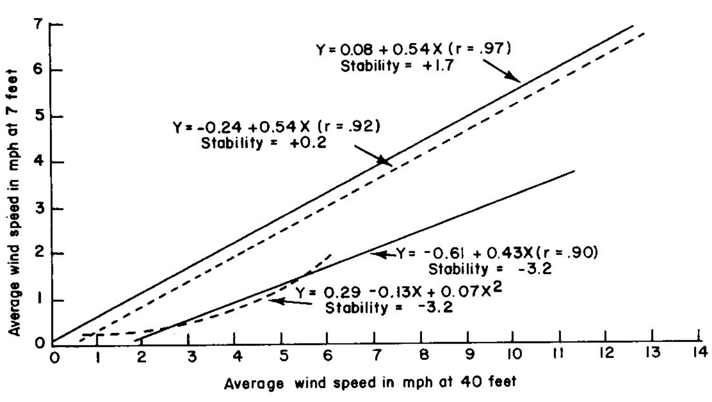


FIGURE 4.—Relationship between wind speed at 40 feet and 7 feet above the ground, above 4-feet high cotton, as a function of air stability at Stoneville, Miss., September 30-November 8, 1960.

The diurnal variation of wind with height above the cotton field is related to the diurnal variation of stability of the air column. Figure 4 shows the relation between winds at the upper and lower levels as a function of stability. The top solid line represents 34 cases of stability between $+1°$ and $+3°$ with an average stability of $+1.7°$. The wind at 7 feet was a little more than half as strong as the wind at 40 feet.

The dashed straight line represents 22 cases of air stability between $+1°$ and $-1°$, with an average stability $+0.2°$. This average stability figure means that the temperature at the 5-foot level averaged nearly the same as the temperature at the 35-foot level. In this case there was practically no wind at the 7-foot level when the wind at 40 feet was 0.7 m.p.h. or less. The wind at 7 feet was usually about half as strong as the wind at 40 feet with a wind of 5 m.p.h. or more at the 40-foot level.

The lower solid straight line represents 24 cases when the air stability was between $-1°$ and $-6°$, or an average of $-3.2°$. All of these cases occurred at night and represent very stable air; i.e., there was little or no vertical mixing of the air in the lower 40 feet above the ground. On this type of night, the wind was practically zero at the 7-foot level with a wind of 2 m.p.h. at 40 feet. With an average wind speed of 10 m.p.h. at 40 feet, the

TABLE 3.—*The average wind speed in defoliated and leafed fields at 2 feet above the ground (cotton plants 4 feet high) and at 7 feet and 40 feet above the ground, Nov. 1–8, 1960, Stoneville, Miss.*

Time (LST)	Undefoliated, 2 feet above ground	Defoliated, 2 feet above ground	7 feet above ground	40 feet above ground
7 a.m.–5 p.m.	0.33	1.29	5.22	9.02
5 p.m.–7 a.m.	0.01	0.04	1.96	5.66

TABLE 4.—*Evaporation from Livingston atmometers and percent increases of black over white at an unobstructed area and within cotton foliage, Sept. 30–Nov. 8, 1960, Stoneville, Miss.*

Exposure	Evaporation		Percent increase of black over white
	White	Black	
32 feet—unobstructed	1012	1591	57.2
26 inches—within leafed cotton	300	349	16.3

wind at 7 feet was only about 3 m.p.h. under stable conditions.

The dashed curved line is a parabola representing the same conditions shown in the lower solid straight line (stable air). This curve is valid only for wind speeds of about 1 to 6 m.p.h. at 40 feet and is included to emphasize the stilling influence of very stable conditions; the air was practically calm at 7 feet with less than 4 or 5 m.p.h. at the 40-foot level.

During the period of November 1–8, 1960, wind readings were made at a height of 2 feet above the ground in fields of defoliated and undefoliated cotton about 4 feet high. During this period, the defoliated field offered only about 30 percent as much surface leaf, stalk, and boll obstruction to wind as did the leafed field. Table 3 shows the average daytime and nighttime wind speed in the defoliated and leafed fields at 2 feet above the ground and at the 7-foot and 40-foot levels.

Practically no wind occurred within the cotton foliage at night unless the prevailing wind was relatively strong, at least 10 m.p.h. Daytime wind speeds in the defoliated cotton averaged only 25 percent of the wind at 7 feet and the wind in the leafed cotton was only 6 percent of the wind at 7 feet. At night, the wind speed in the defoliated cotton was only 2 percent of the 7-foot wind while the wind in the leafed field was less than 1 percent of the 7-foot wind.

Sunlight variation.—The difference between the amount of water evaporated from a white and a black Livingston atmometer gives an indication of sunlight or solar radiation [8]. Table 4 shows the total evaporation from the white and black atmometers at 32 feet (unobstructed location) and at 26 inches (within a leafed field) and the percentage of increase in evaporation of the black over the white.

At the unobstructed location, evaporation from the black atmometer totaled 57 percent more than from the white atmometer. Within the leafed field, evaporation from the black atmometer totaled 16 percent more than from the white atmometer. The percentage increase in the leafed field amounted to only 28 percent of the percentage increase at the unobstructed location. This 28 percent can be assumed to approximate the amount of sunlight that reached the inner zone of a leafed cotton field. Less than a third of the sunlight that was available to the top of a 4- to 5-foot cotton plant was available to the middle of the plant.

Both wind and vertical air currents are at a maximum in the daytime and are usually quite small at night. Wind increases with increasing height and with decreasing amounts of leaf obstruction. Sunlight is much reduced within the leaf canopy. Higher humidity and consequently higher seed cotton moisture content in well leafed fields, as compared with defoliated fields, is in part related to the absence of wind and sunlight in the leafed area.

4. DEW INTENSITY

Dew is a frequent and important cause of wet cotton and must be considered in designing a cotton harvest program. The daily probability of rain is under 20 percent while the probability of dew is over 80 percent in the Delta during the harvest season.

Dew was collected at the observation site on thin, painted, metal sheets. On nights with heavy dew, approximately 2 cm.^{3} of water condensed on each 100 cm.^{2} of surface. This is assumed to be fairly representative of dew that formed on cotton plants and is the moisture equivalent of about 0.01 inch of rain. For purposes of this report dew was classified as: none, light, moderate, heavy. Rain fell on 5 nights of the 40-day observation period, September 30–November 8, 1960 and these intervals were omitted from this portion of the report.

Huschke [9] lists the following conditions as favorable for dew formation: " (a) a radiating surface, well insulated from the heat supply of the soil, on which vapor may condense; (b) a clear, still atmosphere with low specific humidity in all but the surface layers, to permit sufficient effective terrestrial radiation to cool the surface; and (c) high relative humidity in the surface air layers, or an adjacent source of moisture such as a lake."

The availability of moisture is very rarely the limiting factor in dew formation in the Delta because of the many lakes and ponds in the area. During periods of extended drought, the availability of moisture is vastly reduced. Many of the lakes and ponds dry out and trees and crops under moisture stress do not supply much moisture by transpiration. During the drought years in the early 1950's the lack of local moisture was a limiting factor in dew formation; however, it has not been a factor in the 3 years of current Weather Bureau experiments in cotton fields.

Relative humidity in relation to dew intensity.—To determine the relationship between relative humidity and

TABLE 5.—*Relative humidity at 5 feet above the ground, 1 foot above defoliated cotton, as related to dew intensity Sept. 30–Nov. 8, 1960, Stoneville, Miss.*

Dew intensity	Average relative humidity 1 a.m.–6 a.m.	Percent of nights relative humidity did not reach 100 percent	Average relative humidity on preceding day		
			10 p.m.–12 midnight	7 p.m.–9 p.m.	1 p.m.–3 p.m.
Heavy	100	0	98	92	42
Moderate	100	0	96	89	43
Light	91	22	78	66	53
None	83	67	83	83	54

TABLE 7.—*Relation of dew intensity and average wind speed in m.p.h. from 5 p.m. to 7 a.m. at two levels above cotton fields at Stoneville, Miss., Sept. 30–Nov. 8, 1960.*

Dew intensity	Average speed 7 feet above the ground or 3 feet above defoliated cotton plants	Average speed 40 feet above the ground
	m.p.h.	*m.p.h.*
Heavy	0.42	2.46
Moderate	.89	2.99
Light	1.75	5.46
None	3.10	6.81

dew intensity on cotton fields, the humidity was measured at a height of 5 feet above the ground, which was 1 foot above the top of a defoliated cotton field. As shown in table 5, the relationship varied with the time of day. After midnight, there was a close direct relation between relative humidity and dew intensity. Between the preceding afternoon's relative humidity and dew occurrence next morning, the relation was inverse. There was very little relation between humidity during the early evening and dew intensity the following morning.

During nights with heavy dew the air remained saturated; relative humidity equaled 100 percent from 1 a.m. to 6 a.m. During 5 of the 7 nights with moderate dew, the humidity was 100 percent continuously during that period, but with light or no dew it was never continuously 100 percent for the 5-hour period.

On nights with heavy dew the average time of saturation was 12 p.m. (midnight) and the latest time of saturation was 1 a.m. With moderate dew, the air reached saturation about 1½ hours later. On nights of light or no dew, the air was saturated for only very brief periods if at all.

Table 5 shows that the highest humidities for nighttime periods before midnight occurred with moderate to heavy dew. In the case of light dew and no dew, higher humidities occurred with no dew. At such times, fairly high humidity in the evening was accompanied by cloudiness but the clouds persisted through the night and prevented the ground from cooling and thereby prevented saturation.

The last column of table 5 shows that low afternoon humidities often preceded high dew intensity. This merely indicates that clear days were usually followed by clear nights and the large diurnal temperature change gave low relative humidities in the day and high values at night.

Cloud cover in relation to dew intensity.—The variable used to represent cloud cover in this experiment was the percent of opaque sky cover, excluding obstruction by fog, from the hours of 7 p.m. through 6 a.m. as measured by the Greenwood FAA station 43 miles to the east. The distance between the two observation points introduces a small error; however, the difference is usually quite small. Table 6 shows that an average of 72 percent opaque sky cover occurred on nights with no dew formation. The effect of lesser cloud amounts was indeterminate.

Wind speed in relation to dew intensity.—Table 7 shows the average wind speed from 5 p.m. to 7 a.m. as recorded at 7 feet above the ground and at 40 feet above the ground. The speed at 7 feet is indicative of conditions 3 feet above defoliated cotton plants and the speed at 40 feet compares with wind observations at airport stations in the area. Moderate to heavy dew was associated with average winds at 40 feet of less than 3 m.p.h., light dew with average winds of 5–6 m.p.h., and no dew with an average of about 7 m.p.h.

Table 8 shows the relation of dew intensity to air stability. On nights with no dew, the average stability was not far from zero; this means that the air in the first 30 feet above the cotton plant was near neutral stability; i.e., vertical motion was possible most of the time. On nights with dew, the air was normally quite stratified and little vertical motion occurred. Occasionally heavy dew occurred on cotton plants while the top of the tower was dry, indicating a very shallow temperature inversion. Since the inversion height is normally above the tower top, the stability measurements of this experiment can differentiate between dew and no dew but cannot be used to forecast dew intensity.

TABLE 6.—*Relation of percent opaque sky cover, excluding fog, as measured by the Greenwood, Miss., FAA station during the hours of 7 p.m. through 6 a.m., to dew intensity at Stoneville, Miss. Sept. 30–Nov. 8, 1960.*

Dew intensity	Percent of opaque sky cover
Heavy	8
Moderate	5
Light	4
None	72

TABLE 8.—*Relation of dew intensity to air stability as measured by the temperature at 5 feet above the ground minus the temperature at 35 feet above the ground from 5 p.m. to 7 a.m. Sept. 30–Nov. 8, 1960, Stoneville, Miss.*

Dew intensity	Average stability
Heavy	−2.49
Moderate	−2.63
Light	−3.90
None	−.27

Combined effect of cloud cover and wind on dew intensity.—Cloud cover and wind speed normally do not undergo extreme changes during the night, but there are exceptions. For example, a thundershower or a front may move through the area during the evening giving gusty winds and cloudy skies up until midnight, while after midnight, clear calm conditions may prevail. Clear calm weather normally produces a moderate to heavy dew. Both cloud cover and wind speed are represented by a nightly average in this experiment; thus it is not possible to account for the rare occurrences of radically changing weather during the night.

Figure 5 shows the four classes of dew intensity as a function of cloud cover and wind speed at 40 feet. In table 6, the lower range of cloud cover shows little relation to dew intensity. Consequently, in figure 5, the classes of dew intensity for cloud cover of less than 20 percent are related almost exclusively to wind speed.

As both wind and cloud cover are regularly forecast, it might be possible to use the relation shown in this graph to make regular forecasts of dew intensity. This has not been tested on independent data.

5. EVAPORATION

Evaporation from a water surface in an enclosed container is a relatively simple process compared with evaporation from a field of cotton. Inside the container, an equilibrium is established between water molecules escaping from the water surface and those returning to the surface. In an open cotton field equilibrium is a rare condition; normally moisture is being taken away by evaporation or added by dew formation.

Evaporation was measured at 3 levels in both defoliated and undefoliated fields during the period 7:45 a.m. to 5:00 p.m. on 35 days without rain, September 22–November 5, 1959. Table 9 shows that evaporation at the 10- and 21-inch levels in the defoliated field was nearly twice that in the undefoliated field. Even at the 54-inch level, which was only 6 inches below the top of the plant, evaporation was greater in the defoliated field.

The evaporation observations during 1960 included the addition of two black Livingston atmometers. Because of the different radiation absorption characteristics of the white and black atmometers, the difference in evaporation between the two atmometers gives a measure of solar radiation. Observations in 1960 also included evaporation readings, both black and white, made on the weather tower shown in figure 2.

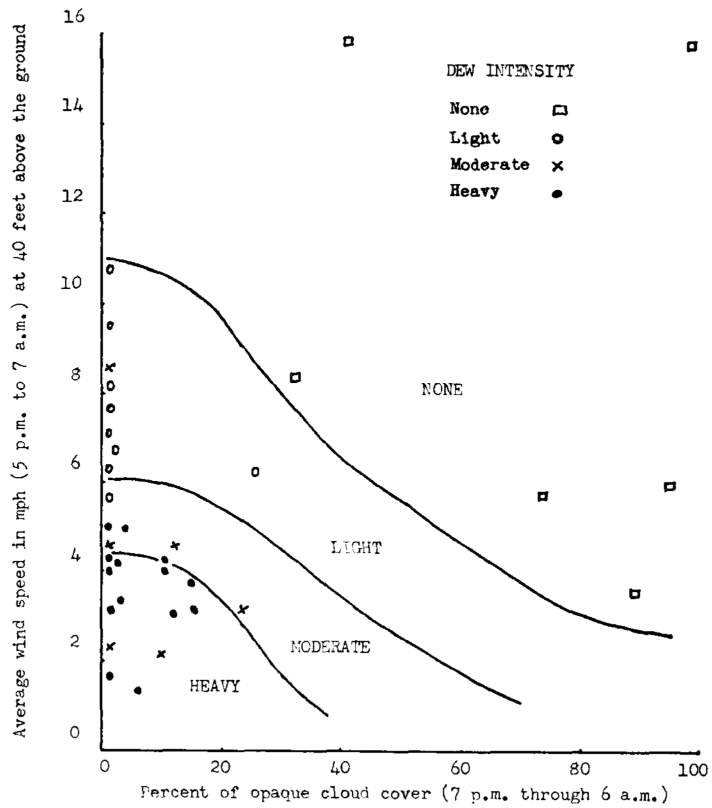


FIGURE 5.—Dew intensity in relation to percent of opaque cloud cover from 7 p.m. through 6 a.m. and to average wind speed in m.p.h. from 5 p.m. to 7 a.m. at 40 feet above the ground, Stoneville, Miss., September 30–November 8, 1960.

Table 10 summarizes evaporation readings made during the period 7 a.m.–5 p.m., September 30–November 8, 1960. Evaporation was directly proportional to the height above the ground and inversely proportional to the amount of obstruction. Within the two types of cotton fields, evaporation was almost twice as great in the defoliated field, in agreement with measurements made the year before.

The variation in evaporation between the 5-foot and

TABLE 9.—*Average evaporation from Livingston atmometers in 5-foot-high defoliated and undefoliated cotton fields on 35 days without rain during the period 7:45 a.m. to 5:00 p.m., Sept. 22–Nov. 5, 1959, Stoneville, Miss.*

Height above ground (inches)	Evaporation (cm.^{3})	
	Undefoliated	Defoliated
10	9.8	18.1
21	10.7	19.2
54	23.1	24.9

TABLE 10.—*Average evaporation from Livingston atmometers at different heights and different exposures during the period 7 a.m.–5 p.m., Sept. 30–Nov. 8, 1960, Stoneville, Miss. The latter two columns relate evaporation at individual locations to evaporation at 5-foot level*

Height	Type	Exposure	Average evaporation	Estimation of 5-foot evaporation	Correlation coefficient
32.2 feet	White	Unobstructed	25.3	$Y=1.31+1.21X$	0.972
32.2 feet	Black	Unobstructed	39.8	$Y=4.51+1.78X$	.982
5.0 feet	White	1 foot above defoliated.	19.8		
26 inches	White	Defoliated	15.9	$Y=0.44+0.78X$	.976
18 inches	White	Defoliated	14.0	$Y=0.28+0.69X$	.970
26 inches	White	Undefoliated	8.9	$Y=-1.74+0.53X$	.935
18 inches	White	Undefoliated	7.5	$Y=-1.77+0.47X$	.892
18 inches	Black	Undefoliated	8.7	$Y=-2.03+0.54X$	.908

32-foot levels was primarily due to stronger winds at the upper level. The variation between readings in fields of different leaf cover was caused by differing relative humidity, amounts of sunshine, and wind speeds.

The fifth column in table 10 contains regression equations which estimate the evaporation at the 5-foot level as a function of the individual location. The last column gives correlation coefficients which show the relation between the evaporation at the various observation points and the evaporation at the 5-foot level. The evaporation at each of the various observation points appears to be closely related to the evaporation at the 5-foot level.

Readings within the leafed field, although highly correlated showed the poorest relation. This lower correlation is believed to have been caused by a slight change in leaf cover that occurred during the experiment, and not by any fundamental difference in relation to measured variables. A light frost occurred October 21 and a few top leaves were killed. They dried up during the last of October and subsequent frosts killed more leaves early in November. Besides offering less resistance to wind and sunlight, the dried leaves late in the season did not transpire as much moisture; thus the sheltered, moist climate that extisted through the first two-thirds of October was modified considerably by the end of the period.

To obtain an estimate of how the evaporation within the leafed field increased during the experiment, the 10-day total evaporation at the 5-foot level was divided into the 10-day total evaporation from the various levels within the cotton fields. Table 11 shows these measures.

Evaporation in the undefoliated cotton field using the 5-foot reading as a standard shows some increase during the third period and a sharp increase during the last 10-day period. This undoubtedly was due to the reduction of leaf cover, and to a lesser extent to the aging of the existing leaf cover as cold weather advanced. One interesting point is that the black atmometer in the leafed field had less evaporation than the white atmometer 8 inches higher during the first 30 days of the period; but, during the last 10 days, the condition reversed. This was caused by the increase in sunlight within the leafed field as the leaf cover gradually became less. For comparison purposes, evaporation at the same heights in the defoliated field are included. Variations occurred there too, but were smaller and in the opposite direction to the changes in the leafed field; this tends to emphasize the drying effect that occurred in the leafed field with the advance of the season.

TABLE 11.—*10-day total evaporation (cm.^{3}) from different instruments within cotton fields divided by the 10-day total at the 5-foot level*

Periods	Defoliated cotton		Undefoliated cotton		
	White		White	White	Black
	26 in.	18 in.	26 in.	18 in.	18 in.
Sept. 30–Oct. 9	0.810	0.719	0.354	0.268	0.341
Oct. 10–Oct. 19	.895	.783	.364	.296	.340
Oct. 20–Oct. 29	.816	.719	.487	.391	.459
Oct. 30–Nov. 8	.752	.668	.544	.508	.572

Evaporation is measured by a number of different methods and each tends to give a different estimate of the same elusive weather element. Pan evaporation was measured regularly at the Stoneville weather station from April 1 to October 31. For the month of October, the evaporation from the 5-foot Livingston atmometer was related significantly, at the 1 percent level, to pan evaporation. Total evaporation from the Livingston atmometer was 710 cm.^{3} and from the pan, 3.44 inches. It is much easier to read 2-cm.^{3} evaporation from the Livingston atmometer than it is to read the comparable evaporation of 0.01 inch from the pan. In addition the Livingston atmometer can be moved more easily. The aerodynamics of the two different evaporimeters are different and it is believed that Livingston atmometers are much better suited to this type of investigation.

To evaluate weather elements that influence evaporation, and thus drying power near cotton plants, various measurements of sunshine, relative humidity, wind, and temperature were related to the daily evaporation at the 5-foot level for the period September 30–November 8, 1960.

Sunshine intensity in total langleys per day and the average relative humidity from 1 p.m. to 3 p.m. at the 5-foot level were found to be related significantly at the 1 percent level to the evaporation. Average wind speed from 7 a.m. to 5 p.m. at the 7-foot level was related significantly at the 5 percent level to the evaporation. No measure of temperature including maximum, minimum, and afternoon average, and no value of air stability was found that gave a reliable estimate of evaporation during the 40-day period in 1960.

The following multiple regression equation relates certain weather measures to evaporation:

$$X_1 = 13.781 + 0.196X_2 - 0.232X_3 + 0.034X_4$$

where X_1 is total evaporation (cm.^{3}) at 5 feet from 7 a.m. to 5 p.m.; X_2 is average wind speed (m.p.h.$\times$10) at 7 feet from 7 a.m. to 5 p.m.; X_3 is average relative humidity (percent, with decimal point ignored) at 5 feet from 1 p.m. to 3 p.m.; X_4 is sunshine intensity in total langleys per day.

The coefficient of multiple correlation for the above equation is 0.913, the standard error of estimate is 3.58. The standard error of estimate for each pair of variables is: wind and relative humidity, 4.04; wind and sunshine, 4.17; and relative humidity and sunshine, 4.71. The combination of wind and relative humidity gives the smallest error, while the combination wind and sunshine is only slightly higher. Sun and relative humidity give the largest error. The reason is the interrelation of the

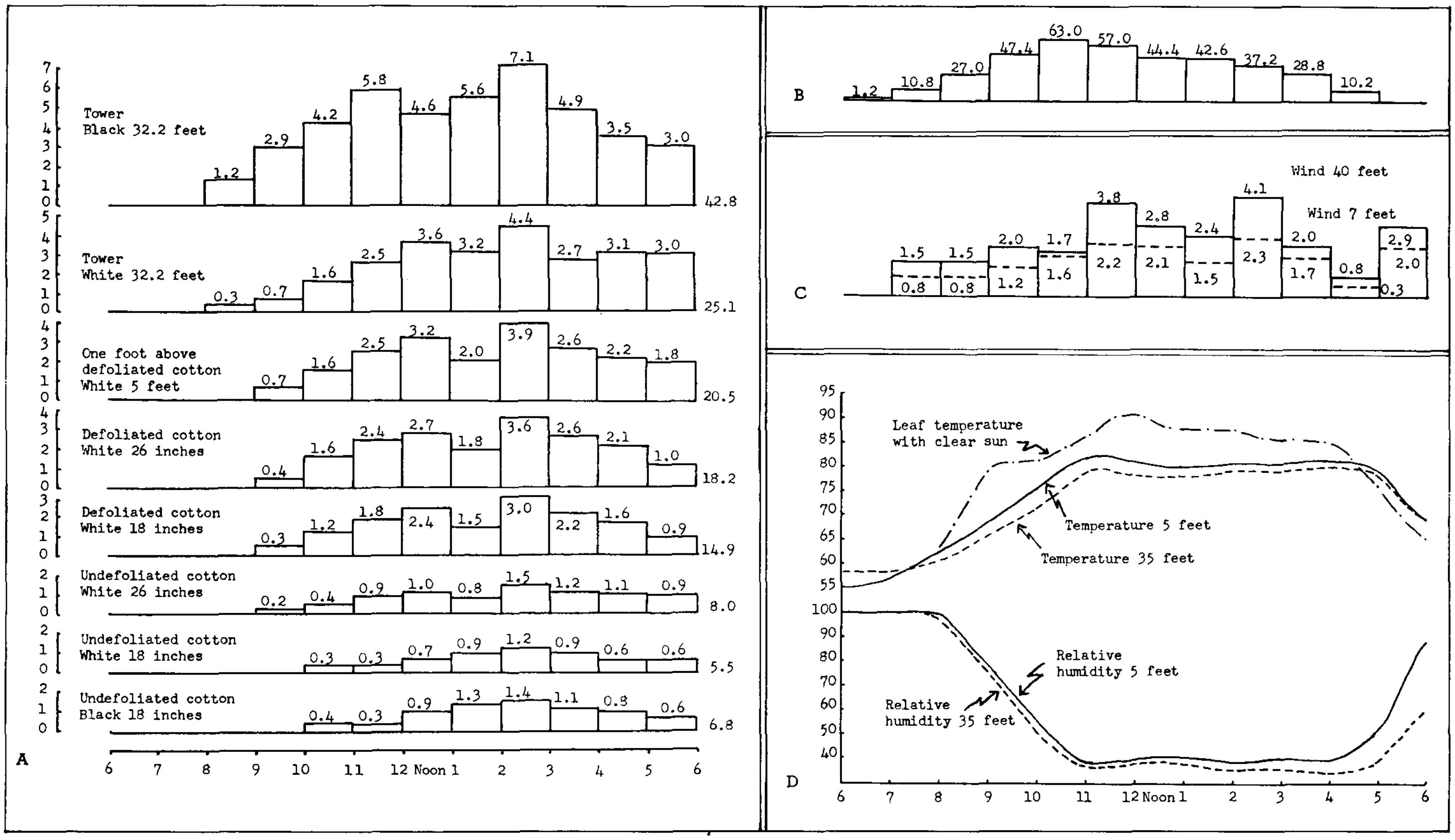


FIGURE 6.—Hourly weather observations in or near cotton fields, Stoneville, Miss., October 12, 1960. (A) Total hourly evaporation in cm.^{3} (B) Total hourly solar radiation in langleys hr.$^{-1}$ (C) Average hourly wind speed in m.p.h. (D) Temperature in °F. and relative humidity in percent.

two variables; i.e., sunny days are generally dry (low relative humidity) and vice versa. The partial correlation coefficients are: wind, 0.65; relative humidity, 0.52; and sunshine, 0.46. Wind is shown to be the most important single factor in the multiple regression equation, despite the fact that it had a smaller simple correlation coefficient. The effect of holding the mutually related relative humidity and sunshine constant is to increase the importance of wind.

Figures 6 A–D show detailed measurements for one day during the experiment, October 12, 1960. High pressure with dry mild air centered over Tennessee extended into the Delta. A few tenths of altocumulus clouds around sunrise cleared by 8 a.m. Small, scattered, fair weather cumulus prevailed from 10 a.m. to 5 p.m. Dew was heavy at 7 a.m., disappearing from defoliated cotton about 9 a.m. and from undefoliated cotton about 10 a.m. Light dew formed again on exposed surfaces on both fields about 6:30 p.m. Such weather is typical of a fairly good cotton picking day in the Delta.

Figure 6A shows hourly evaporation totals at different heights and different exposures. As indicated earlier, evaporation increased with increasing exposure (lack of leaf and stalk obstruction) and with increasing height above the ground. Besides the variation in total amount, it is of interest to note the time lag of maximum evaporation that occurred within the cotton fields as compared with more exposed locations. The first measurable evaporation occurred on the tower during the hour 8–9 a.m. Measurable evaporation did not occur at the 18-inch level in the leafed field until 2 hours later, 10–11 a.m. Evaporation at the exposed locations showed an early peak during the hours of 11 a.m. to 1 p.m., with another peak from 2–3 p.m. The early peak, although greatly damped in amplitude, extended to the 26-inch level in the leafed field. At the 18-inch level in the leafed field, there was a single maximum at 2–3 p.m., but the black atmometer did show a rather sharp increase from 11 a.m. to 1 p.m.

Figure 6B shows the greatest hourly solar radiation, 63 langleys, occurred from 10 to 11 a.m. Scattered small cumulus clouds caused sunlight to fluctuate considerably after 11:20 a.m. The maximum hourly evaporation at all levels occurred from 2–3 p.m., which was several hours after the time of maximum solar radiation.

Figure 6C shows an early maximum of wind from 11–12 a.m. The greatest wind was measured from 2–3 p.m., which was also the period of greatest evaporation at all levels.

Figure 6D shows the temperature and relative humidity variation throughout the day. Temperature reached a maximum and relative humidity a minimum about 11

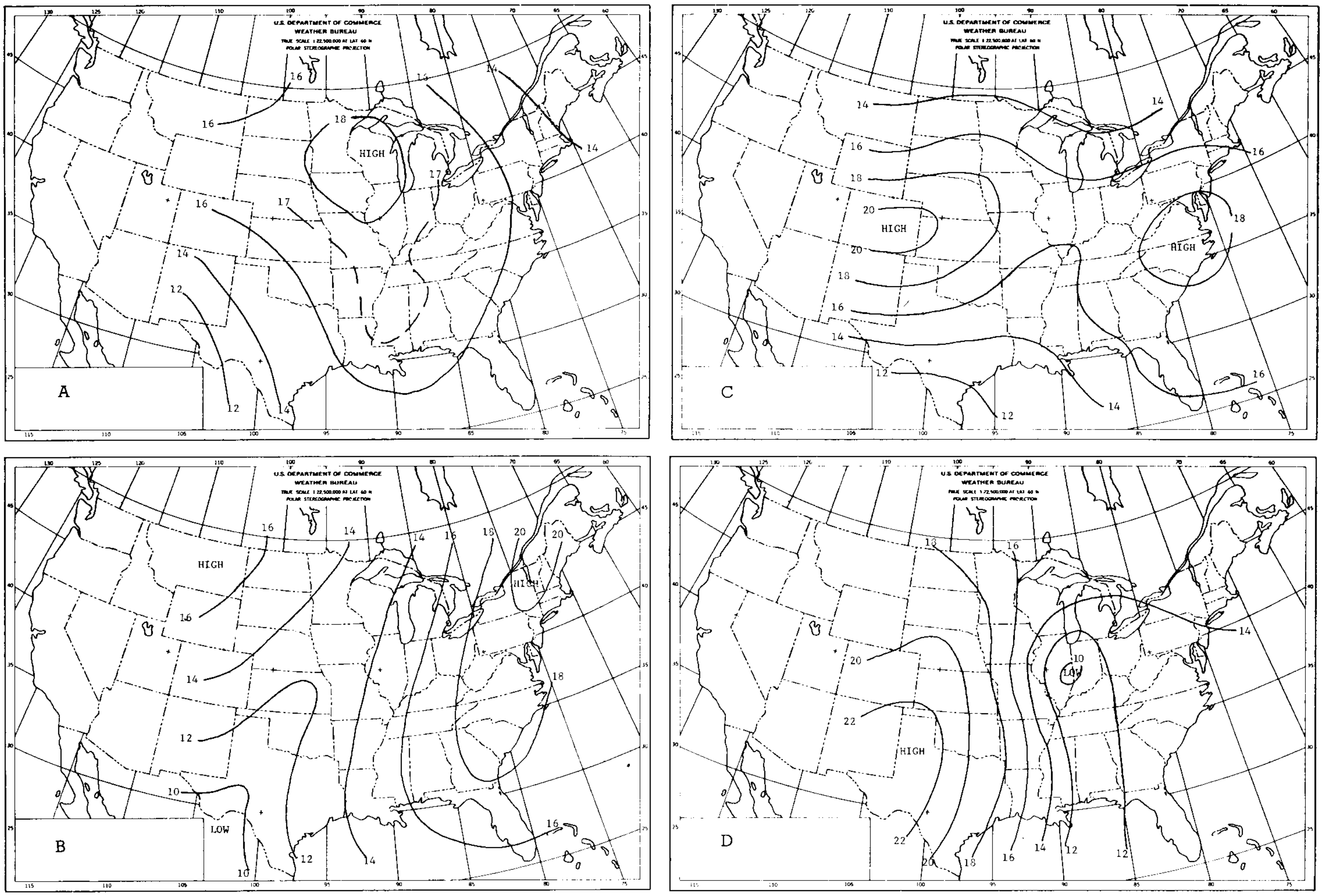


FIGURE 7.—Average sea level pressure in millibars at 12 a.m. (A) Heavy dew. (B) No dew with southerly winds. (C) No dew because of rain. (D) No dew with northerly winds. Stoneville, Miss., September 30–November 8, 1960.

a.m. and only minor changes occurred until after 4 p.m.

Leaf temperature readings as shown in figure 6D, were made when the sun was not obscured by clouds. Small electrically recording temperature probes, normally used to measure temperature inside fruit, were taped onto the bottom portion of leaves. Leaves that were measured were alive and green but rather dry and apparently transpiring very little. The maximum difference between the leaf temperature and the air temperature at 5 feet occurred shortly after noon, during a period of maximum sunlight. At that time, the leaf temperature was 11° higher than the surrounding air temperature. Differences between leaf and air temperature on this day were typical of readings made on several other fairly clear days. The leaf temperature was a little below the air temperature early in the morning until the dew was nearly all evaporated (usually between 8 and 10 a.m.), then the leaf was warmer than the air until just before sunset. When the leaf no longer received direct solar radiation (usually 4–5 p.m.), it became colder than the air. During the period of dusk, with clear skies, the leaf was about 5° cooler than the air, which of course is a necessary condition for dew formation. On the day shown in figure 6D, dew had begun to form on well exposed leaf and stalk surfaces by 6:30 p.m.

6. RELATION OF DEW AND EVAPORATION TO PRESSURE PATTERNS

Dew intensity and sea level pressure patterns.—Figure 7 shows the average sea level pressure pattern for 13 cases of heavy dew. High pressure is the significant feature; however, there are two different locations of the high center that give dew in the Delta. The small knob of high pressure that appears over central Mississippi in figure 7A reflects four cases where a high pressure system just to the south of the Delta was associated with heavy dew. The larger and more pronounced high pressure system to the north represents the average center on the nine other nights of heavy dew.

Figure 7B shows the average sea level pressure pattern for four nights of no dew. Figure 7C shows the pattern of five nights on which rain fell and no dew formed and figure 7D shows the average pattern for the two remaining nights of no dew.

The nights comprising figure 7B were grouped together because the wind was from the south in the Delta. The wind at 40 feet averaged 4.3 m.p.h. and the cloud cover averaged 73 percent. North wind prevailed during the nights grouped in figure 7D; here the wind was much stronger, 11.8 m.p.h., and the cloud cover was about the same, 72 percent.

It is interesting to note that the three maps of no dew seem to form a series showing a trough of low pressure, or a front, moving from northwest through the Delta. With an approaching front, increasing cloudiness prevents dew. When the front is overhead, rain combined with cloud cover prevails, and immediately after the front has passed, gusty winds prevent dew.

Strong frontal passages as far south as the Delta are rare in September and the first half of October; during that period cloudiness and wind associated with weak fronts or instability lines are the usual conditions limiting dew formation. Later in the year, active fronts and more pronounced low pressure systems are the limiting factors. In most cases, cloudiness is the limiting factor in dew formation before the middle of October. It is very rare to have a night with no dew before mid-October. After the middle of October, wind is the main limiting factor and nights with no dew become somewhat more frequent.

Evaporation and sea level pressure patterns.—Figure 8A shows the average sea level pressure pattern at 12 a.m. on the days when evaporation totaled 30 cm.^{3} or greater. Figure 8B shows the same data for six days when the evaporation totaled less than 10 cm.^{3} The first map, showing strong drying conditions, features a low pressure trough from the Texas Panhandle through southwestern Nebraska to Lake Superior, a high pressure center just south of the Delta, and relatively strong pressure gradient just north of the Delta that would bring dry air and rather gusty winds from the west. Figure 8B, showing poor drying weather, features a weak trough from southern Texas through western Arkansas to Lake Michigan, high pressure over Colorado and the Virginias, and a weak pressure gradient over the Delta that would bring light, moist south to southeast winds over the Delta.

The charts indicate that the strength of the westerly wind over the area just west of the Delta is the most important synoptic feature. Strong westerly winds give good drying conditions, while southeasterly winds give poor drying conditions. As a measure of the strength of the westerly winds, the 12 a.m. sea level pressure at Galveston (p_{GLS}) was subtracted from the pressure at Sioux City (p_{SUX}) and the following regression equation developed:

$$\text{Evaporation (at 5 feet)} = 19.49 - 0.07\,(p_{SUX} - p_{GLS})$$

The correlation coefficient relating the sea level pressure difference between the two stations to the evaporation has been about the same magnitude as the correlation coefficient relating the local wind speed at 7 feet to the evaporation reading.

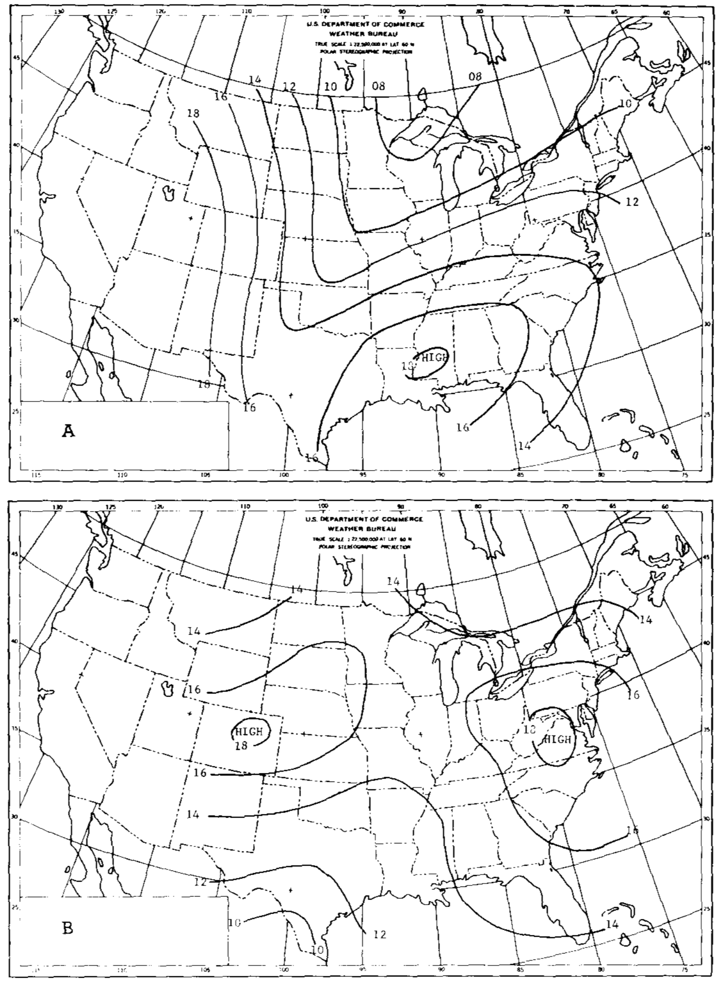


FIGURE 8.—Average sea level pressure in millibars at 12 a.m. (A) Six days with evaporation from Livingston atmometers at 5 feet above the ground (one foot above defoliated cotton) of 30 cm.^{3} or more. (B) Six days when evaporation was less than 10 cm.^{3} Stoneville, Miss. September 30–November 8, 1960.

7. ESTIMATING PICKING TIME

Figure 9 shows a cotton picking guide designed jointly with the Cotton Harvesting Section of the U.S. Department of Agriculture. The graph is based on average conditions measured during the falls of 1958 and 1959. The three major variables are: time of year, leaf cover, and dew intensity. Minor modifications are made by considering cloudiness and wind. By using the guide, an individual farmer in the Mississippi Delta can make an early morning estimate of when his cotton will be dry enough to harvest.

8. CONCLUSION

Observations taken within cotton fields during the harvest season indicated that relative humidity variation was strongly influenced by the amount of leaf cover. Daytime humidities were higher deep within a leafed plant zone than near the top. Relative humidity at midday averaged 9 percent lower in defoliated fields

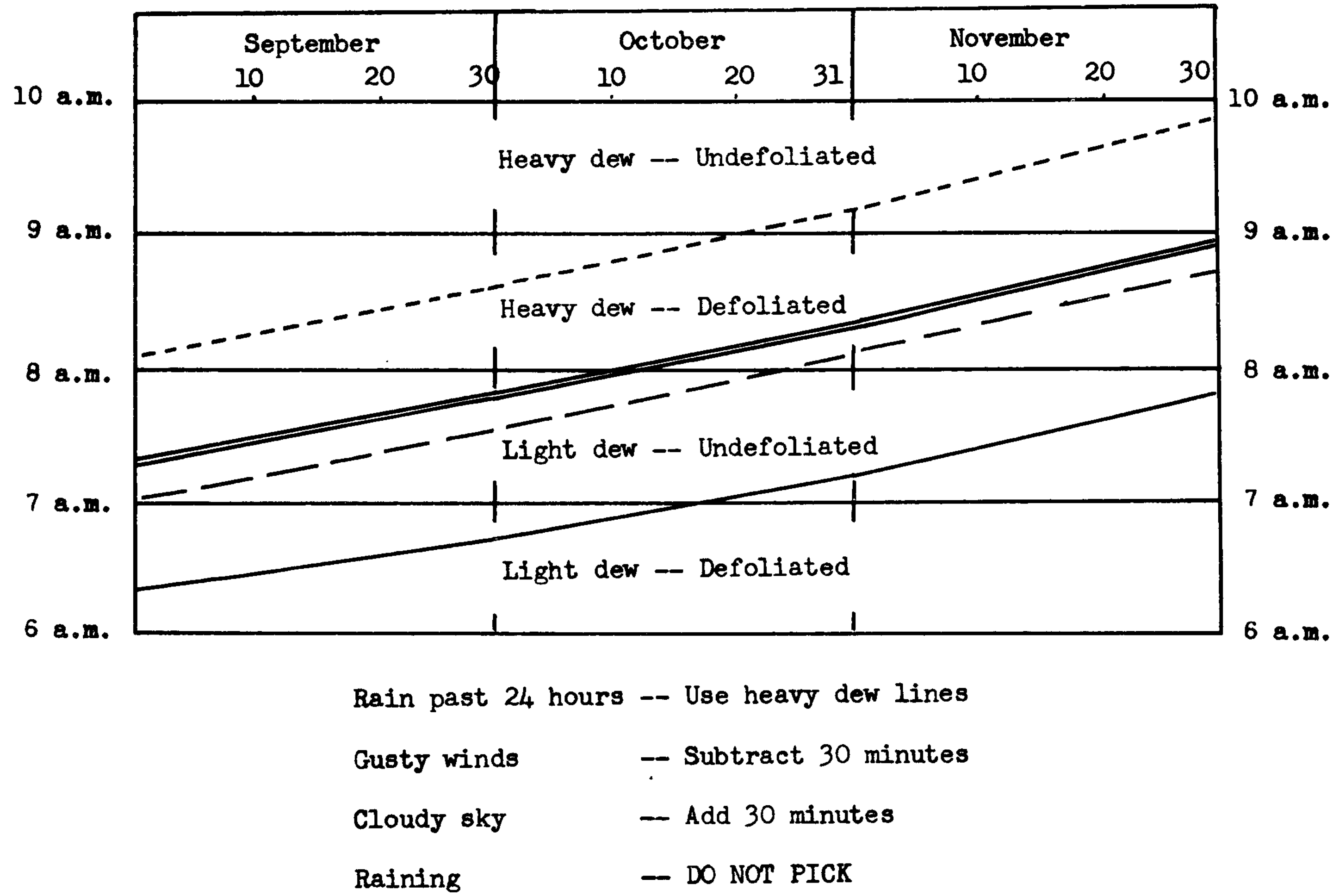


FIGURE 9.—Daily guide for beginning mechanical cotton picking, Mississippi Delta Area, designed jointly by the Cotton Harvesting Section, ARS, and the Weather Bureau.

than in leafed fields. It normally stayed below 50 percent, an estimate of "safe" picking conditions, for an additional hour in defoliated fields.

Wind and sunlight within a cotton field were found to be inversely proportional to the amount of leaf cover. The decrease of wind and sunlight within the cotton field was related to the variation of relative humidity at the same level. Sunlight was much reduced within a leafed cotton field. Less than a third of the sunlight measured at the top of 4-foot-high cotton penetrated to within 1½ feet of the ground. Wind increased with increasing height above the ground and decreasing amounts of obstruction. At 2 feet above the ground in the cotton fields, daytime winds in a leafed field averaged only 6 percent of the wind at 7 feet above the ground and in a defoliated field they averaged 25 percent of the wind at 7 feet above the ground.

Dew is the most frequent wetting factor in cotton fields at harvest time. Heavy dew occurred with clear skies, light winds, stable air, and high nighttime humidities in cotton fields. In the cases studies here, a large high pressure system at sea level over, or north of, the Delta was associated with heavy dew; low pressure, especially in the form of a northeast-southwest trough in the area, was associated with no dew.

High values of evaporation were favored by strong sunlight, low humidities, and strong winds. Evaporation was twice as great in a defoliated field as in a leafed field. In addition to the difference in total evaporation, there was a time lag in evaporation in the leafed field. A strong westerly flow of air, as indicated on the sea level map, was the best synoptic predictor of high rates of evaporation in the Delta.

The cotton picking guide designed jointly with the Cotton Harvesting Section of the U.S. Department of Agriculture gives the farmer an early morning estimate of when his cotton will be dry enough to harvest. Further studies relating weather variations to seed cotton moisture variation and objective techniques for forecasting dew and evaporation are expected to refine the guide with an end in mind of giving the farmer a technique for planning his picking activities at least 12 hours in advance.

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